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RAINFALL AND WATER YIELDS OF THREE SMALL, FORESTED CATCHMENTS IN NORTH-EAST VICTORIA, AND RELATION TO FLOW OF LOCAL RIVERS

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ABSTRACT: The rainfall and water yield of three small, contiguous forested catchments (0.46 to 1.13 km^2) in north-eastern Victoria were compared. Consistent differences of up to 10% in rain gauge catch over short distances were observed. In wet periods, the catchments may return 60% or more of rainfall as streamflow. When annual rainfall is below about 700 mm, streamflow effectively ceases. Two of the catchments show evidence of water loss relative to the third; this is approximately proportional to the streamflow and varies from about 0.2 mm per day in the driest period to about 2.5 mm per day in the wettest period. The small streams all show similar seasonal variation to the nearby Buffalo, Dandongadale, and Rose Rivers, while the water yields per unit area of the river catchments are quite similar to the two "leaky" catchments. However, inadequacies in the rainfall information in these preclude water balances. It is concluded that the seasonal variation of the small streams can be regarded as broadly representative of the larger rivers in this environment, with deviations likely to be due to unknown meteorological factors.

The rationale behind small catchment research is that other catchments of similar size in the same environment will respond to meteorological inputs similarly, and that the response of the larger catchments in the area is at least not dissimilar to that of the smaller catchments. However, because of the expense and difficulty in obtaining data sets of adequate quality there is relatively little specific information on this matter in Australia. The purpose of this study was to examine the water yield of three small, forested catchments (0.46-1.13 km^2) in north-eastern Victoria, and to compare this to that of three larger catchments (176-425 km^2) in nearby and somewhat similar environments. The three small catchments (Clem, Ella, and Betsy Creeks) comprise the Cropper Creek Hydrologic Project Area of the Department of Conservation, Forests & Lands; this was established to provide hydrologic information on forest practices. The three larger streams are the Buffalo River (at Abbeyard), and the Rose and Dandongadale Rivers near their confluence ("Matong North"). These rivers were selected because gauging records were available and the flow records were unaffected by the influence of substantial irrigation diversion, river regulation, or agricultural developments. Table 1 gives details and Fig. 1 shows the locations of the catchments. Fig. 2 gives a plan of the Cropper Creek Project Area, a description of which can be found in Bren *et al.* (1979). In 1980, Clem Creek catchment was converted to radiata pine (*Pinus radiata* D. Don) to study the effects on water yield, peak flows, sediment yields, and nutrient budgets. This work is based on the pretreatment data.

SMALL CATCHMENT HYDROLOGY

The small catchments have a dry sclerophyll open forest that generally has little merchantable timber. The bedrock consists of a tightly folded, fractured, and steeply dipping sequence of Ordovician sediments. The overlying soils have a high permeability and low erodability. They are shallow on the ridges with a high surface cover of fractured rock, while gully soils are deep loams formed from transported slope deposits. A number of studies have examined aspects of the hydrology of the small catchments, with a summary of these reported in Bren and Turner (1985). These studies considered slope hydrology, groundwater movement, stream-channel hydraulics, and runoff generation. The work showed that streamflow mainly resulted from groundwater discharge emanating from porous catchment slopes. This groundwater is recharged by rainfall and is stored in the weathered rock zone. The small streams commence as rather elongated "springs". The rainfall response is complex and varies with distance downstream from the spring. At the springhead the flow varies only slowly during rainfall, reflecting a stabilising effect due to the convergent, semi-circular springhead catchment. Most of the more rapid variation in streamflow results from subsurface flow entering from the catchment flanks. This behaviour is discussed in detail in Bren and Turner (1985).

Hewlett, Fortson and Cunningham (1984) included rainfall and runoff data from Clem Creek in a study of storm flow responses from small forested catchments located in humid environments. The data set also included 14 catchments from North America and two from South Africa. The analysis showed that, on virtually all catchments, the most important predictor of the storm response was the storm rainfall. Knowledge of short-term rainfall intensities (e.g. maximum 1 h rainfall intensity, etc.) gave little improvement in predictions of storm response provided the storm rainfall was known. An inference drawn from this study is that relatively short-term variations in rainfall intensity have little influence on the resultant runoff compared to the total volume of storm

TABLE 1

CHARACTERISTICS OF THE STUDY CATCHMENTS

	Small Catchments		Large Catchments	
Gauging Stations	120° V-notch weirs with water level recorder.		Buffalo R. Dandongadale R. Rose R.	– Natural control – Concrete weir – Concrete and rock weir
Catchment Area	Clem Ck Ella Ck Betsy Ck	– 0.46 km² – 1.13 km² – 0.44 km²	Buffalo R. Dandongadale R. Rose R.	– 425 km² – 181 km² – 176 km²
Private property	Nil		Buffalo R. Dandongadale R. Rose R.	– 24 km² – Nil – 56 km²
Gauging Authority	Dept. Cons., For. & Lands.		Rural Water Commission	
Catchment Vegetation	Dry sclerophyll vegetation with mainly peppermint species & well developed gully vegetation		Largely dry sclerophyll with small areas of agricultural land and some alpine areas in catchment headwaters.	
Catchment Topography	Moderately steep.		Moderately steep to steep foothills; some mountainous areas at heads of rivers	
Land Use	Non-commercial forest.		Mainly non-commercial forest with some agriculture and logging.	
Rainfall Stations	5 within Project Area Ella Creek gauge used in study.		No reliable stations in catchments	
Precipitation	Rain, occasional light snow.		Rain, winter snow in upland areas.	

rainfall. Of particular interest was the statistical similarity of the rainfall response of all catchments.

Bren and Turner (1979) measured overland flow on the catchment slopes during storm rainfall and found that it was small and, at best, could only account for less than 5% of the measured stream flow response during storm rainfalls. More typically it was less than 1%, and most of the overland flow measured appeared to be associated with raindrop splash. The lack of overland flow appeared to reflect the high infiltration capacity of the slopes relative to the rainfall intensities encountered in this environment. Vertessy (1984) carried out a similar study in a burnt eucalypt forest near Warburton (Vic.), and obtained similar results.

Bren and Leitch (1985) examined the water yield ("runoff") from a stretch of forest road near the project area. The flow from a road drainage culvert was passed through a measurement weir, and then discharged

TABLE 2

REGRESSION EQUATION OF CLEM CREEK MEAN DAILY FLOW (C, l/s) AS A FUNCTION OF ELLA CREEK (E) AND BETSY CREEK (B) MEAN DAILY FLOWS (l/s), AND RATIO OF THE CORRESPONDING CATCHMENT AREA

Regression equation	Ratio of catchment areas	Correlation coefficient
$C = 0.473E + 0.714$	0.41	0.985*
$C = 1.06B + 2.041$	1.04	0.952*

* Denotes significance of the correlation coefficient at $P = 0.001$.

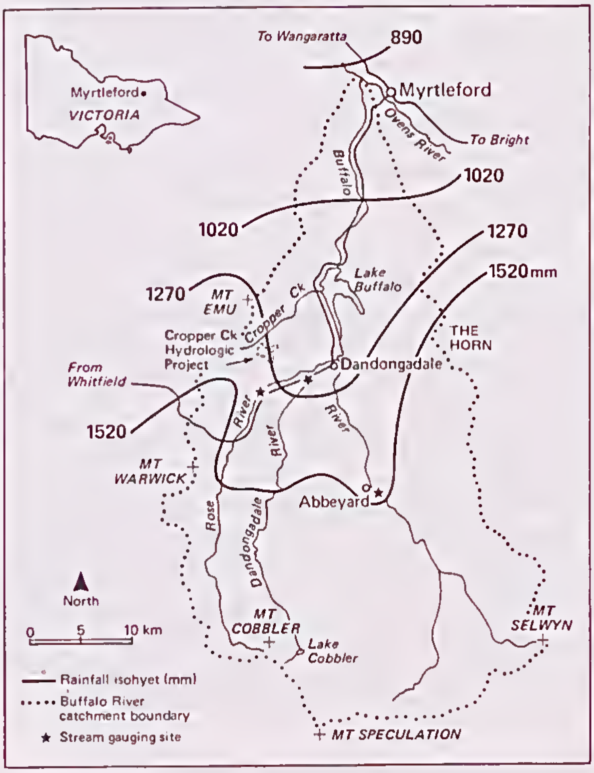

Fig. 1—Plan showing the location of the Cropper Creek Project area in relation to the Buffalo River catchment, and approximate location of isohyets.

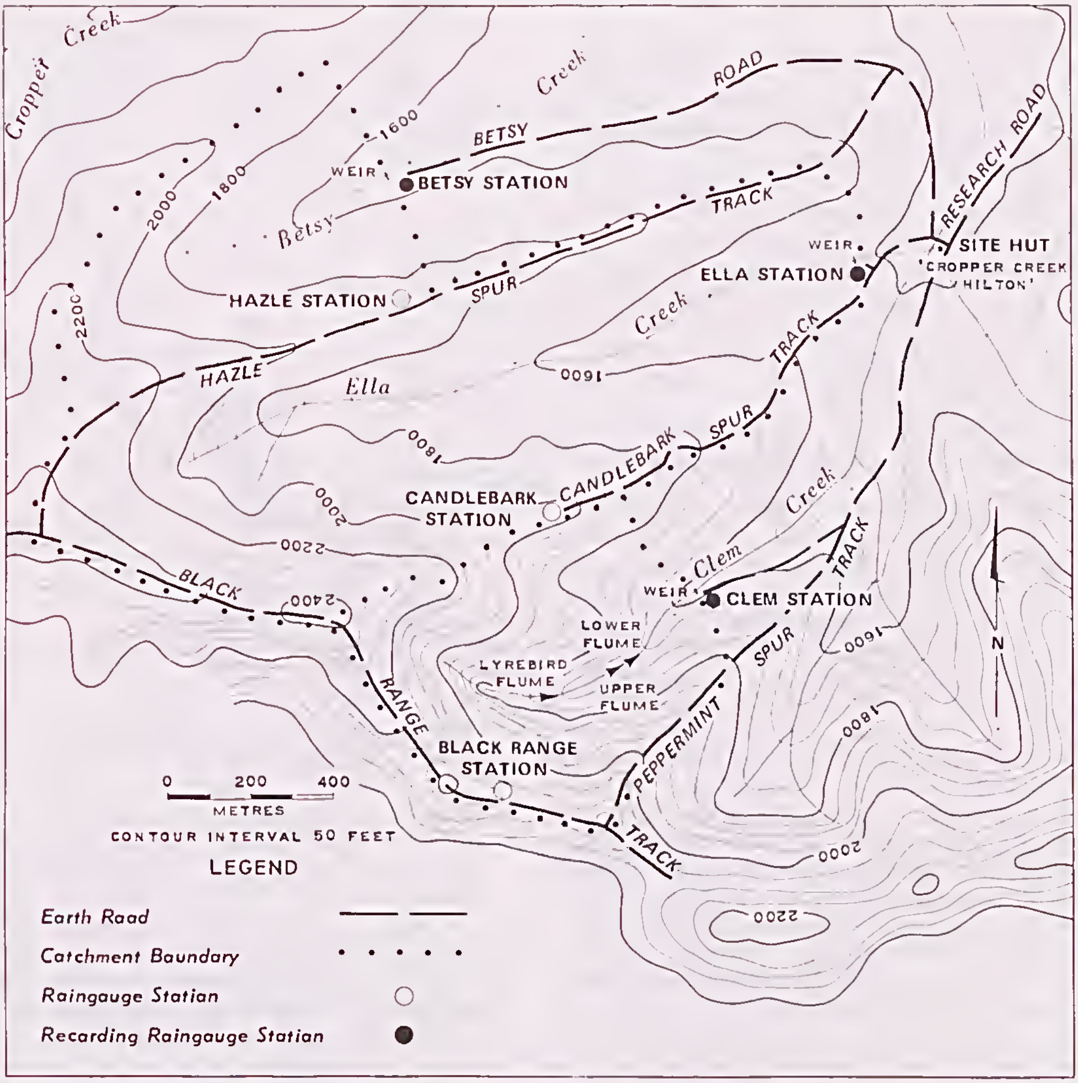

Fig. 2—Plan of the Cropper Creek hydrologic project area.

uniformly over a 5 m width of slope. Some 5 m downslope, a collection gutter collected surface flow and again passed this into a measurement weir. Continuous records of above-road runoff and rainfall intensity were also maintained. The volume of storm runoff attributable to a given storm rainfall ("stormflow") per unit road area was best predicted by the depth of rainfall, while the peak flow per unit road area was best predicted by the maximum 1 h rainfall intensity. The results were compared with the models of stormflow and peak flow generation derived by Hewlett, Fortson and Cunningham (1984) for Clem Creek. It was concluded that the presence of a length of road in this catchment would lead to a small increase in stormflow for small and moderate storms but would make little difference for larger storms. However, the road would possibly make a substantial contribution to the peak flow achieved for all storm-sizes, although timing differences in reaching peaks could be a complicating factor. A theoretical analysis showed that a road which occupied 2% of Clem Ck catchment area and discharged waste water into the stream would give about 10% more stormflow but would often double the peak flow generated, although the relative effect diminished with storm size. The passage of runoff across a short length of natural forest slope appeared to make little difference to the flow, despite the known high infiltration capacity of undisturbed slopes and the unsaturated state of the soil. Observation suggested that the fine sediment carried by the water quickly blocked infiltration pathways into the soil. It was concluded that if infiltration of the outflow of road culverts is to be obtained then special measures to adequately distribute the water over the slope and to maintain infiltration pathways may be necessary.

THE LARGER CATCHMENTS

The topography and vegetation of substantial tracts of the lower parts of the three larger catchments are similar to those of the smaller catchments. The Land Conservation Council (1974) ascribe the same vegetation types (variants of "open peppermint forest") to virtually all the catchments, with the exception of small areas of montane forests in the vicinity of Mt Cobbler and Mt Selwyn. The upper tracts of the rivers tend to be more mountainous and rocky than the Cropper Creek area. It is concluded that the Cropper Creek catchments are similar to the most common land-type in the larger catchments. Although both the Rose and Buffalo Rivers have blocks of private property (Table 1) much of this is uncleared or semi-cleared only.

The streamflow data were collected by the Rural Water Commission as part of their river gauging projects.

DID UNUSUAL RAINFALL PATTERNS OCCUR DURING THE STUDY?

The rainfall and streamflow data for the small streams were collected as part of the Cropper Creek Hydrologic Project and cover the period from its inception (1975) until the end of the pre-treatment phase (1980). Because of the sparseness of settlement in the larger catchments there is no continuous record of rainfall within or of variation across the catchments, with the nearest elevated stations being at Mt Hotham or Mt Buller. Fig. 1 shows isohyets estimated by the Land Conservation Council (1974), indicating a substantial rainfall gradient across the Buffalo River catchment. It is concluded that the rainfall measured at Cropper Creek is likely to be a good indicator of relative rainfall variation over time, but that it will underestimate precipitation on the larger catchments by an unknown factor.

Fig. 3 shows the historical (1897-1979) distribution of annual rainfalls at Myrtleford and the rainfall during the period of measurement. Analysis of these data and the 1975-9 rainfall data collected at Ella Creek Weir shows that:

i. there is a 2.9% probability of annual rainfall being higher than the highest experienced during the study period and 15.0% probability of lower than the lowest during the study period;

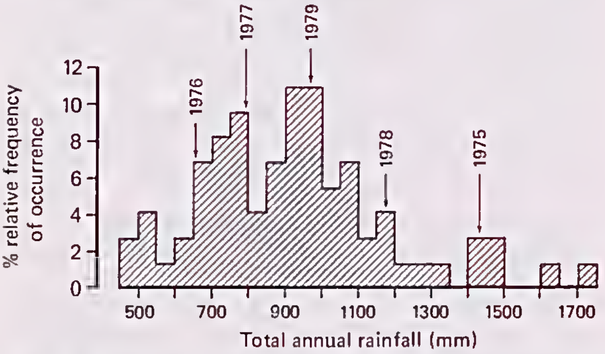

Fig. 3 – Historical distribution of rainfall (1897-1977) at Myrtleford, and rainfall during the period covered by this study.

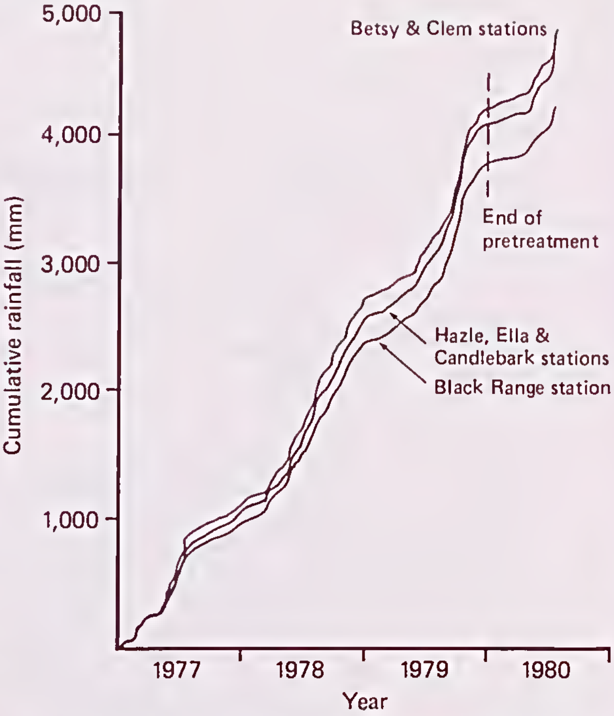

Fig. 4 – Cumulative rainfall at measurement stations within the project area from Jan. 1977 to July 1980.

ii. monthly rainfall at Ella Creek was well correlated ($r^2 = 0.923$) with rainfall at Myrtleford, and about 38% higher, confirming the rainfall gradient shown on Fig. 1;

iii. the frequency distribution of one day rainfalls at Myrtleford during the study period was close to that of the historical distribution, but the frequency distribution of substantial two and three day storms showed that these were slightly under represented in the 1975-79 data;

iv. no absolute extreme one, two, or three day rainfalls occurred during the study period although substantial local flooding occurred on a number of occasions; and,

v. within the project area consistent differences of up to 10% in gauge catch were recorded. Fig. 4 shows the cumulative rainfall at the various stations for a 30 month period. There is a very constant relativity between gauges, but this cannot be easily related to elevation or topography, although the more elevated gauges do appear to receive less rainfall. It is not known whether such differences were due to gauge exposure or reflected real variations across the catchments. Corbett (1967) showed that such variation can be regarded as "normal". The Ella Weir gauge gave a reading about the mean of all gauges and hence has been used in this study. The implications of this variation are discussed below.

We concluded that the historical rainfall distribution with time was reasonably sampled during the measurement period, and that it was unlikely that any of the

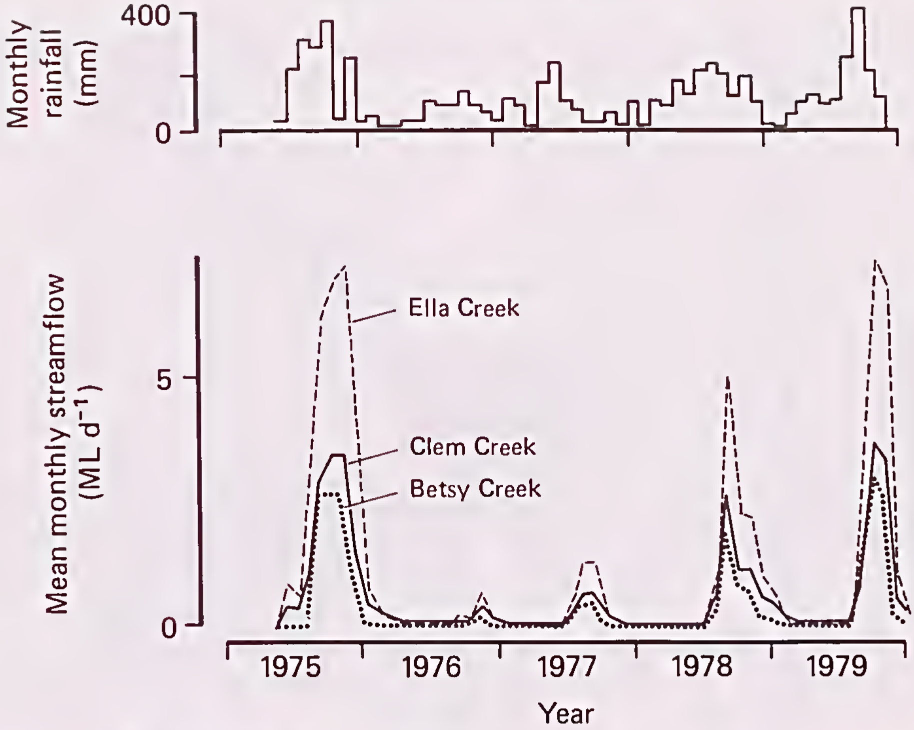

Fig. 5 — Rainfall and mean monthly streamflow at Cropper Creek.

findings reported here are attributable to anomalies in the rainfall events.

SEASONAL VARIATION OF STREAMFLOW AT CROPPER CREEK

Fig. 5 shows the rainfall at Ella Ck Gauge and the streamflow (averaged over calender months) of all streams. The annual pattern is of high winter and spring flows combined with low (or absent)? summer and autumn flows. Only Clem Ck exhibited sustained flow, while the two other streams had a propensity to dry up in summer. Ella Ck would usually cease flowing in early summer and recommence flowing after a substantial storm (*c.* 100 mm) occurred in autumn, and Betsy Ck would usually only flow in reasonably direct association with sustained substantial rainfall. However, once flowing, their rainfall response was approximately proportional to the catchment size. Table 2 shows regression equations of average daily flow in Clem Ck as function of average daily flow in Ella and Betsy Cks respectively, and the corresponding ratio of catchment areas. The similarity of the regression gradient to the ratio of the catchment areas reflects the apparent strong dependence of catchment yield on area. The positive constants of the regressions reflects that in summer Ella and Betsy Cks cease flowing because of seepage loss. At other than the lowest flows, the streams exhibited a substantial constancy in their relative response. Fig. 6 shows double-mass plots for the three streams. During the period of active flow of Ella and Betsy Cks the relation appears to be constant while the "flattenings" in the plots are caused by cessation of flow. The small variations in the slope of the double-mass lines when all streams are flowing indicate that the deep seepage losses vary from year to year. It is concluded that the major difference between the water yield of the streams was the loss of water from Ella and Betsy Cks.

A number of reasons have been considered for such variations in the relative yield. These include: (i) local variations in rainfall causing Clem Ck catchment to receive more than Ella or Betsy Ck. This is rejected because Fig. 4 suggests that Betsy and Clem catchment received similar rainfall. (ii) "deep seepage" out of the catchment which did not pass through the measurement weirs. This could be either at substantial depth or, alternatively, at relatively shallow depths moving downstream. There was no evidence of substantial measurement station "leakage"; however, the weirs were founded on the parent rock which is known to store and transmit groundwater, and it is likely that the steep country would lead to substantial subsurface flow below the cutoff walls of the weirs. It is stressed that given an environment in which water is stored and transmitted in the weathered rock zone, such flow must be regarded as normal and not regarded as a deficiency in the gauging stations. (iii) Suggested possible differences in soil types or depths on the catchments. However, there were no observable differences in the soil or soil depth between the three catchments.

An interesting possibility raised by the persistence of Clem Ck at times of low rainfall, and when other streams had ceased to flow, was whether Clem Ck was somehow "capturing" waters from other streams. We

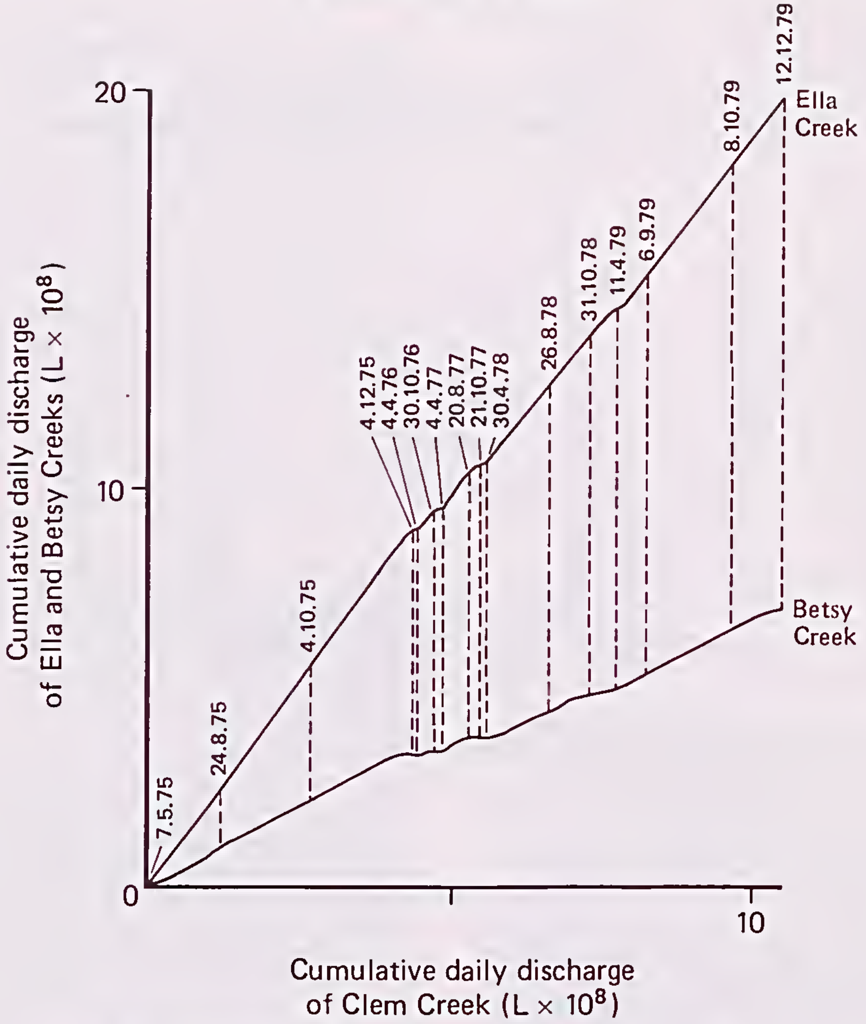

Fig. 6—Double mass plots of Ella and Betsy Creeks with Clem Creek.

could find no hydrograph anomalies which would support such a contention; nor was their any topographic or geologic information which would suggest why such a capture should be occurring. However, in view of the role of the catchment rock material in storing and transmitting groundwater it cannot be ruled out, although our catchments would not be particularly different from most other forested catchments.

Finally, it behoves us to comment on the idealised concept of a "sealed catchment"—i.e. a catchment in which water loss is only by evapotranspiration or by streamflow. If such a thing exists, then Clem Ck must be regarded as the closest approximation in this environment. However, we take the more pessimistic view that in an environment governed by groundwater processes there is no particular reason to suppose that hydrologic gradients should not pass water to adjacent catchments underground; inadequacy of measurement techniques to assess this is a major deficiency.

CATCHMENT WATER BALANCES AT CROPPERS CREEK

Table 3 and Fig. 7 show the annual rainfall and runoff for the three streams at Cropper Ck; below about 700 mm annual rainfall, streamflow would appear to cease. Above this value, the marginal rate of contribution of rainfall to runoff appears to be between 60% and 75%.

Formally, the water balance for a small catchment may be expressed as:

$$T=S+E+I+D+C \qquad (1)$$

where T = total precipitation, mm; S = streamflow, mm; E = evapotranspiration, mm; I = interception storage of rainfall, mm; D = deep seepage, mm; and, C = increase of storage of water within the catchment, mm.

In general, only T and S can be measured with any degree of accuracy. By judicious selection of the period over which the water balance is evaluated, C can be

TABLE 3

ANNUAL RAINFALL AT THE PROJECT AREA AND ANNUAL RUNOFF FOR EACH OF THE THREE STREAMS IN THE CROPPER CREEK PROJECT, NORTH-EASTERN VICTORIA

Year	Annual rainfall (mm)	Annual runoff (mm)		
		Clem	Ella	Betsy
1975*	1867	911	764	639
1976	863	109	58	78
1977	1016	149	100	71
1978	1625	463	342	280
1979	1497	627	489	450

* Data only available from mid-May 1975.

zero. Given this, estimates can be made of the catchment loss (E+I+D) by subtraction of observed streamflow from rainfall during the period. The data from Cropper Ck shows two such periods when estimates can be made: late autumn to late spring (the "wet period") and late spring to late autumn (the "dry period"). The actual period of time varies from year to year but can be broadly categorised by defining the "wet" period as that time during which Betsy Ck is flowing (average 4.4 months per year). The water balance and catchment loss for Clem Ck using this indicator is shown in Table 4. These data show that total evapotranspiration and interception losses are variable with higher losses in "wet" periods, which is possibly due to higher interception losses and the greater availability of soil moisture in this period. The very low "catchment loss" in the summer of 1976 must be regarded as reflecting the moderately severe drought and low water availability at this time.

Fig. 8 shows the monthly ratio of runoff to rainfall (per cent) for the three streams. The catchment yield efficiency is seasonal, with figures of 60% being commonly achieved. Values above 100% reflect the influence of a wet month preceding a dry month, although most storm response is generated within 3 or 4 days of the

TABLE 4

RAINFALL, RUNOFF AND CATCHMENT LOSS* AT CLEM CREEK FOR PERIODS OF HIGH AND LOW SOIL-MOISTURE STATUS, AS INDICATED BY THE PRESENCE OR ABSENCE OF FLOW AT BETSY CREEK, NORTH-EASTERN VICTORIA.

Period	Condition of Betsy Creek	Rainfall (mm)	Clem Creek		
			Runoff (mm)	$\frac{\text{Runoff}}{\text{Rainfall}}$ (%)	Catchment loss* (mm day^{-1})
31.7.75 to 22.1.76	Flowing	1303	798	61.2	2.9
23.1.76 to 28.6.76	Dry	163	36	22.1	0.8
29.6.76 to 4.11.76	Flowing	542	45	8.3	3.8
5.11.76 to 28.6.77	Dry	705	34	4.8	2.8
29.6.77 to 23.9.77	Flowing	313	108	34.5	2.4
24.9.77 to 5.7.78	Dry	764	43	5.6	2.5
6.7.78 to 5.1.79	Flowing	987	420	42.6	3.1
6.1.79 to 9.8.79	Dry	531	47	8.9	2.2
10.8.79 to 9.12.79	Flowing	953	569	59.7	3.1

* Catchment loss = Evapotranspiration + Interception + Deep seepage.

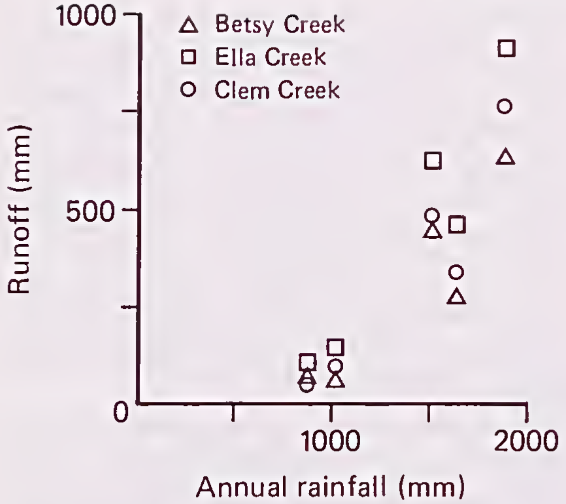

Fig. 7—Annual water yield for the three small streams as a function of annual rainfall.

causal storm rainfall. A general similarity between this ratio and the annual flow variation (Fig. 5) can be seen, reflecting the increased yield from a "wet" catchment compared to a "dry" catchment. The difference in daily water yield (expressed in mm per day) between Clem and Ella and Betsy Cks respectively allows the relative seepage loss for these catchments to be computed. If the arguable assumption is made that Clem Ck is "sealed" then this gives a measure of the absolute water loss. Fig. 9 shows the estimated relative seepage as a function of time. It is concluded that: (i) Betsy Ck has a substantially greater seepage rate than Ella Ck during the recharge period; and, (ii) An increased rate of seepage is associated with an increased mean monthly streamflow (by comparison with Fig. 5)

Thus, in winter, deep seepage may exceed 2 mm per day while in summer, deep seepage loss is about 0.2 mm per day on Ella and Betsy catchment. The data, combined with the information from Table 4, suggest that deep seepage is similar to transpiration loss in winter but is rather less in summer. The fate of this water is unknown. Nahm (1982) states that the Buffalo Valley is known to be a source of recharge for the Murray Groundwater Basin, and it is possible that this deep seepage recharges these aquifers.

RELATION BETWEEN PERIODIC WATER YIELD IN SMALLER AND LARGER STREAMS

The question of whether a small catchment used for research adequately represents the hydrologic processes governing the behaviour of larger local catchments is both important and difficult. Pilgrim *et al.* (1982) made a detailed examination of the effect of catchment size on runoff relations, and concluded "that while general relationships will exist between small and large catchments no closely defined and simple relationships are likely . . . Without consideration of the factors reviewed here, study of relationships between small and large catchments cannot rise above empiricism and be more than

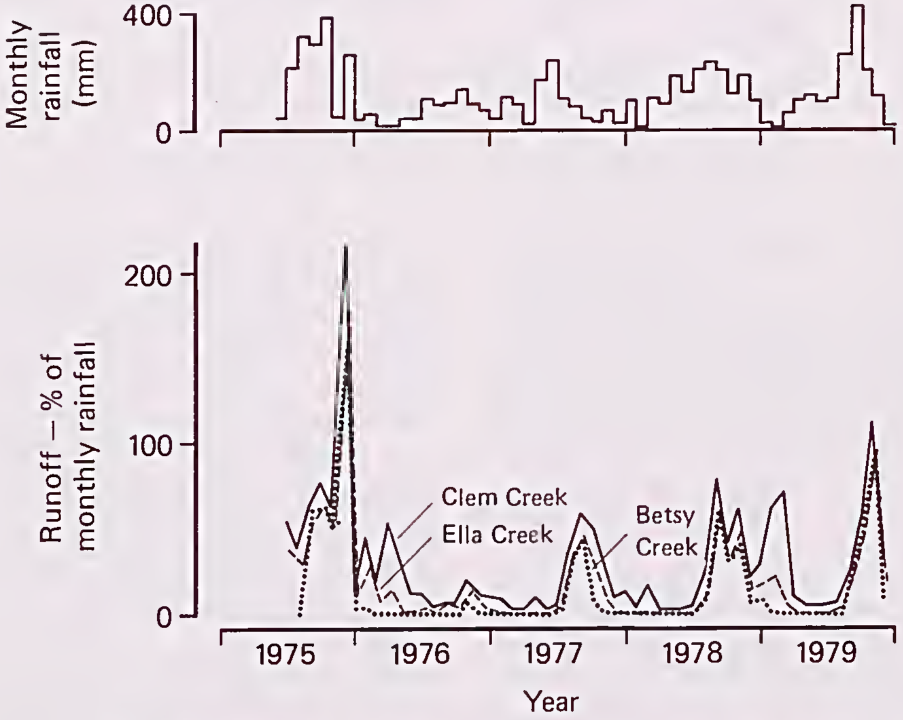

Fig. 8—Monthly ratio of runoff to rainfall for the three small streams.

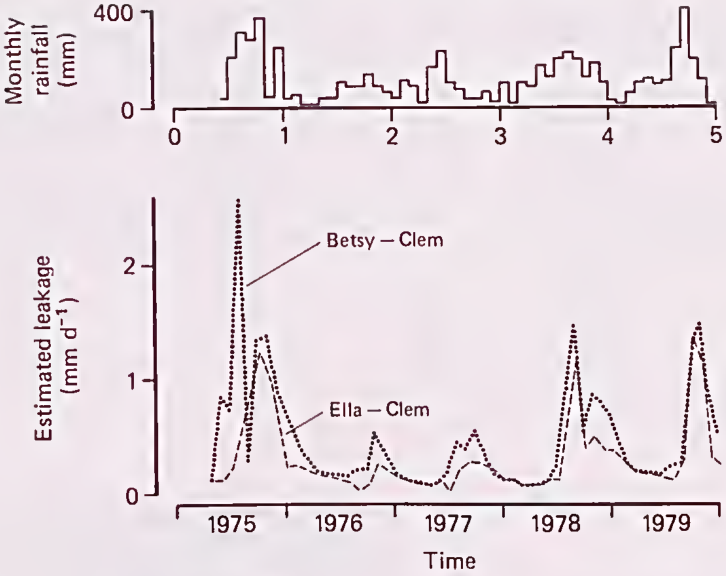

Fig. 9—Estimated seepage loss from Ella and Betsy Creeks as a function of time.

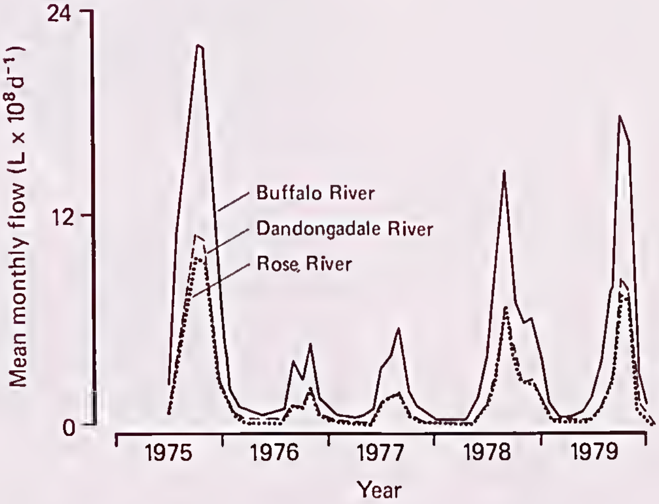

Fig. 10—Mean monthly streamflow of the three larger streams.

site specific". To this end, the study examined whether the Cropper Ck catchments could be regarded as broadly representative of the flow in the larger local streams.

Fig. 10 shows the mean monthly streamflow of the Rose, Dandongadale and Buffalo Rivers; the similarity between these and the mean monthly flow of the smaller streams (Fig. 5) is apparent. Examination of the daily flow in each of these systems, as a function of daily flow in Clem Ck, showed that, overall, the flow in the large and small streams were well-correlated, but that the variance of flow in each system was about proportional to the mean monthly flow. Thus the flow in the small streams could not be regarded as an accurate predictor of flow in the large streams at periods of higher flow. Fig. 11 shows the double-mass plots between each of the larger rivers and Clem Ck. The results suggest, at best, a constant long-term relation but with significant seasonal variation. It is concluded that the same general pattern of daily and monthly flow variation exists in the two sets of catchments but that variations attributable to unmeasured factors preclude the use of the

TABLE 5

RELATIONSHIPS BETWEEN ANNUAL WATER YIELD AND RUNOFF IN LARGER CATCHMENTS CLOSE TO CROPPER CREEK AND ANNUAL WATER YIELDS AND RUNOFF IN CLEM CREEK

Station	Catchment Area km^{-2}	Area as times Clem Ck. area. (1)	Yield of water as times Clem Ck. yield. (2)	Yield per unit area as a ratio of yield per unit area from Clem Ck*
Rose R.	176	379	288	0.76
Dandongadale R.	181	390	282	0.72
Buffalo R.	425	915	704	0.77
Ella Creek	1.13	2.44	1.87	0.77
Betsy Creek	0.44	0.96	0.68	0.71

* i.e., Col. (2)/Col. (1).

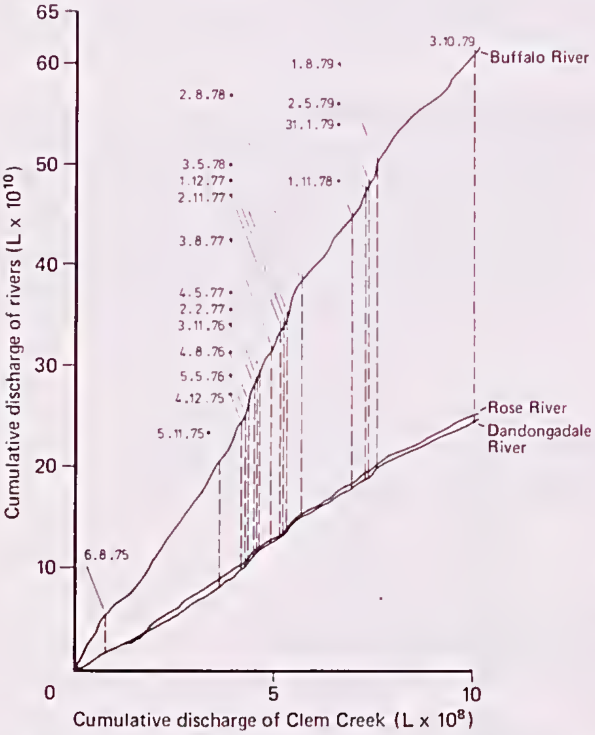

Fig. 11—Double mass plots showing cumulative flow in the larger rivers as a function of the cumulative flow in Clem Creek.

smaller streams as highly-accurate predictors of the larger streams. Major factors would be rainfall variations, the presence of snow, and the size and shape of the catchments.

Table 5 shows the water yield per unit area of all catchments in relation to the yield per unit area from the Clem Ck catchment. The results indicate the larger catchments produce an overall average quite similar to that produced by Ella and Betsy Cks. However, the rainfall gradients across the larger catchments means that use of Cropper Ck rainfall data probably underestimates total rainfall on the catchments and that a crude water balance cannot be computed. Given the imperfections of routine gauging measurements of larger rivers, the water outputs per unit area from the catchments are surprisingly close to those of Ella and Betsy Cks. It is concluded that water yield and general response from the streams at Cropper Ck are broadly representative of the larger streams, although Clem Ck is probably closer to the concept of the "sealed catchment" than the average stream in this area. Achieving a higher level of accuracy in such studies is not feasible without installation of a hydrometeorological network in this region.

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